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Operational Amplifiers Tutorial

WITH SIMPLE POWER SUPPLY

The single feed mode has become very important in systems powered from a single power supply, because it reduces the cost of circuits with operational amplifiers and also makes it easier to use on mobile devices. In this tutorial we will look at various ways that can power amplifiers circuits using operational amplifiers with single power supply (single rail).

The diagram of a sound amplifier, which operates with a single power supply shown in Figure 16. In this circuit one end of the signal source connected to the right input terminal of the operational amplifier, and the other end connected to the bias voltage VBias.

The load resistance (RL) and R1 also associated with the bias voltage. The voltage at the right input terminal, VP, is equal to:

Vp = VBias + Vin

The voltage at the reverse input terminal VN, is equal to:

VN = VD + VP but because,

Vd = 0 we have:

VN = VP = Vin + VBias

without an input signal

Vin = 0, so therefore

Vn = Vp = VBias

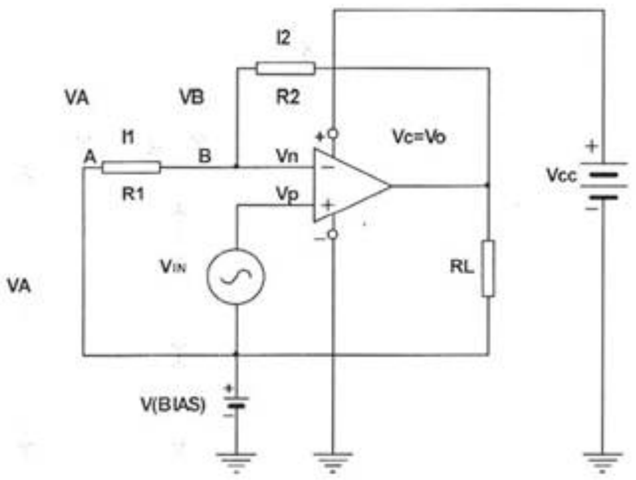


Figure 16. Amplifier with single power supply.

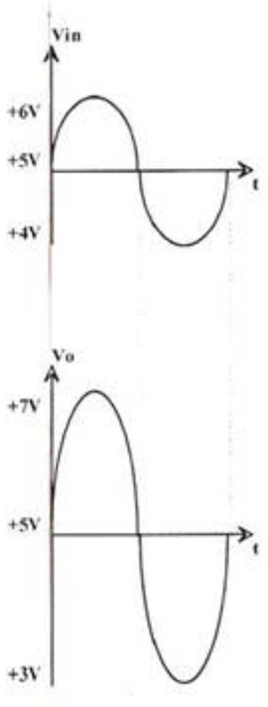


Figure 17. Input and output waveforms of the amplifier of Figure 16.

The bias voltage (VBias) is typically equal to half the voltage of the power supply. The output voltage of this amplifier can be calculated as follows:
The current I1, which flows through the resistor R1, is approximately equal to the current I2, which flows through the resistor R2, and thus I1 = I2. The current flowing through R1 is equal to the difference voltage across R1 divided by the value of R1, ie

$$I_1 = \frac{V_{R1}}{R_1} = \frac{V_B - V_A}{R_1}$$

In this circuit VB is the voltage applied to the right end of R1, and VA is the voltage applied to the left end of R1.
From the figure 16 we see that:
VB = VP but VP = VBias + VIN, thus:
VB = VBias + VIN
We also have VA = VBias so:

$$I_1 = \frac{V_{R1}}{R_1} = \frac{V_B - V_A}{R_1}$$

$$I_1 = \frac{(V_{BIAS} + V_{IN}) - V_{BIAS}}{R_1}$$

$$I_1 = \frac{V_{IN}}{R_1}$$

Similarly, the current I2 flowing through the resistor R2, is equal to the difference voltage across the R2.
i.e. VR2 = VO - VB divided by the value of R2
We also have VB = VBias + VIN, thus:

$$I_2 = \frac{V_O - V_B}{R_2} = \frac{V_O - (V_{BIAS} + V_{IN})}{R_2}$$

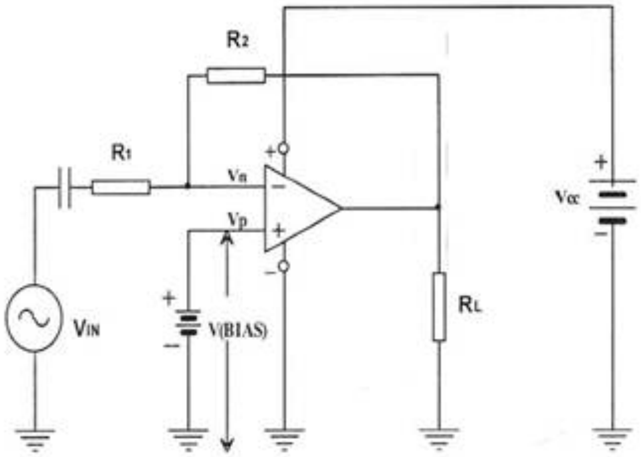


Figure 18a. AC amplifier with simple power supply.

Since I1 = I2, we obtain:

$$\frac{V_{IN}}{R_1} = \frac{V_O - (V_{BIAS} + V_{IN})}{R_2}$$

$$\frac{V_{IN}}{R_1} = \frac{V_O}{R_2} - \frac{V_{BIAS}}{R_2} - \frac{V_{IN}}{R_2}$$

Rearranging we get:

$$\frac{V_O}{R_2} = \frac{V_{IN}}{R_1} + \frac{V_{IN}}{R_2} + \frac{V_{BIAS}}{R_2}$$

$$\frac{V_O}{R_2} = V_{IN}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) + \frac{V_{BIAS}}{R_2}$$

$$\frac{V_O}{R_2} = V_{IN}\left(\frac{R_1 + R_2}{R_1 R_2}\right) + \frac{V_{BIAS}}{R_2}$$

By multiplying both sides of this equation with R2 we get:

$$V_O = V_{IN} R_2 \left(\frac{R_1 + R_2}{R_1 R_2}\right) + \frac{R_2}{R_2} \cdot V_{BIAS}$$

$$V_O = V_{IN} \left(\frac{R_1 + R_2}{R_1}\right) + V_{BIAS}$$

$$V_O = V_{IN} \left(1 + \frac{R_2}{R_1}\right) + V_{BIAS}$$

So in the absence of an input signal, ie when VIN = 0, the above equation becomes

$$V_O = 0\left(1 + \frac{R_2}{R_1}\right) + V_{BIAS}$$

or VO = VBias

So in the absence of an input signal, the input terminals and the output terminal of the operational amplifier have the same voltage (VBias).

If an input voltage 2 volts peak to peak, is applied to the amplifier shown in Figure 16, R1 = R2, and VCC = 10V, then when the input signal is at the positive peak value of +1V, the output voltage will be:

$$V_O = V_{BIAS} + \left(1 + \frac{R_2}{R_1}\right) \cdot V_{IN}$$

$$V_O = \frac{V_{CC}}{2} + \left(1 + \frac{R_2}{R_1}\right) V_{IN}$$

$$V_O = \frac{V_{CC}}{2} + 2 \cdot V_{IN}$$

$$V_O = 5V + 2V = 7V$$

When the input signal changes is at its highest negative value -1V, then the output voltage equals:

$$V_O = V_{BIAS} + \left(1 + \frac{R_2}{R_1}\right) \cdot V_{IN}$$

$$V_O = 5V + (2) \cdot (-1V) = +3V$$

So when the input signal changes from -1V to +1V, the output voltage varies from +3V to +7V.

Figure 17 shows waveforms of the input and output. Notice that the first term in equation 1 represents the voltage gain of a conventional amplifier using a double power supply. The voltage gain is given by the following relationship:

$$A_V = 1 + \frac{R_2}{R_1}$$

In a conventional non-inverting amplifier, which operates with double supply, the bias voltage VBias is equal to 0 volts, and the output voltage is given by the following equation:

$$V_O = V_{IN}\left(1 + \frac{R_2}{R_1}\right)$$

AC POWER AMPLIFIER with simplified power supply

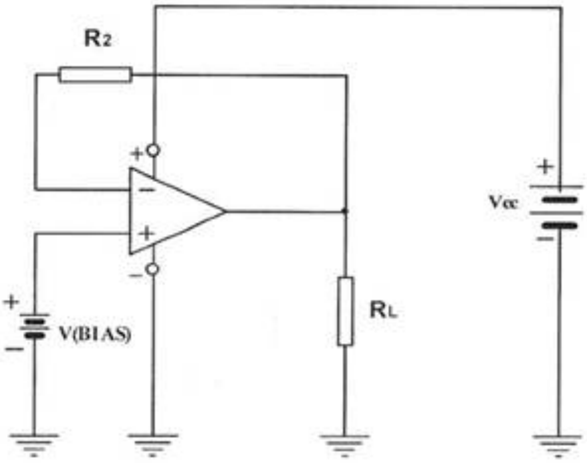


Figure 18b. DC Equivalent of circuit 18a.

Figure 18a shows an AC amplifier that works with a single power supply. In this amplifier the load RL, and the signal source are connected directly to the earth and not with the VBias voltage.
Therefore, the voltage applied to the input (VP) of the operational amplifier is equal to the voltage bias (VBias). The voltage in the reverse input VN, is equal to:

VN = VD + VP

And since in an ideal operational amplifier, VD = 0, we have:

VN = VP

Therefore, both inputs of the operational amplifier having the same voltage (equal to VBias). The input capacitor (Cin) blocks the flow of direct current through the resistor R1.
Therefore, on the direct current circuit of Figure 18 is equivalent to the circuit shown in Figure 18b, which is a voltage follower with voltage gain equal to the unit (AV = 1). Therefore, the constant voltage applied to the input is equal to VBias and the voltage at the output is equal to:

V0 = AV x VBias = 1xVBias

Therefore, the two inputs and the output of the operational amplifier have the same voltage (VBias). If VBias = VCC / 2, then the inputs and the output are located between +Vcc and ground (0 volts), and therefore the amplifier allows the positive and the negative change at the output signal. The output voltage of the amplifier can be determined as follows: The current I1 flowing through the resistor R1 and the capacitor CIN is equal to the current I2 flowing through resistor R, so we say:

I1 = I2

The current flowing through R1 is equal to the voltage difference between the combination of the range R1 and CIN, ie we have:

$$I_1 = \frac{V_A - V_B}{Z_1}$$

Where VA = VIN,
VB = VP = VD + VBias = VBias (because VD = 0)

Also:

$$Z_1 = R_1 + \frac{1}{j\omega C_{IN}}$$

So:

$$I_1 = \frac{V_{IN} - V_{BIAS}}{Z_1}$$

The current I2 is equal to

$$I_2 = \frac{V_B - V_O}{R_2} = \frac{V_{BIAS} - V_O}{R_2}$$

Since I1 = I2 we have:

$$\frac{V_{IN} - V_{BIAS}}{Z_1} = \frac{V_{BIAS} - V_O}{R_2}$$

$$\frac{V_{IN}}{Z_1} - \frac{V_{BIAS}}{Z_1} = \frac{V_{BIAS}}{R_2} - \frac{V_O}{R_2}$$

From the above equation we get:

$$\frac{V_O}{R_2} = -\frac{V_{IN}}{Z_1} + \frac{V_{BIAS}}{R_2} + \frac{V_{BIAS}}{Z_1}$$

$$\frac{V_O}{R_2} = V_{BIAS}\left(\frac{R_2 + Z_1}{R_2 \cdot Z_1}\right) - \frac{V_{IN}}{Z_1}$$

By multiplying both sides with R2 we have:

$$V_O = V_{BIAS} \cdot R_2\left(\frac{R_2 + Z_1}{R_2 \cdot Z_1}\right) - \frac{R_2}{Z_1} \cdot V_{IN}$$

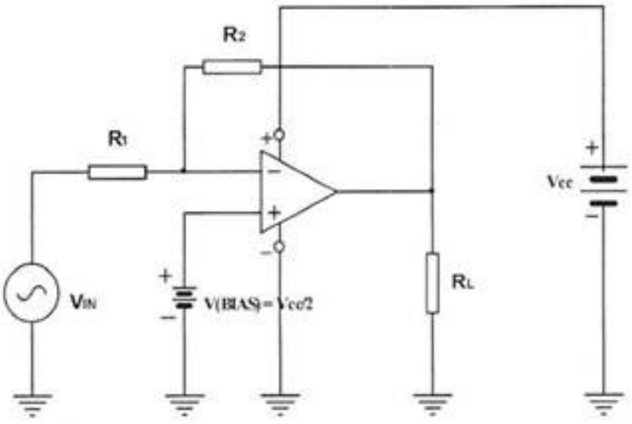


Figure. 19

Note that the expression in the first part in brackets of equation 2, represents the voltage gain of an amplifier to correct AC wiring, and the second part in brackets represents the second voltage gain of an amplifier in reverse AC wiring. Substituting the value of Z1 in the above equation we get:

$$V_O = V_{BIAS}\left[\left(\frac{R_2}{R_1 + \frac{1}{j\omega C_{IN}}}\right) + 1\right] - V_{IN}\left(\frac{R_2}{R_1 + \frac{1}{j\omega C_{IN}}}\right)$$

At rest, VIN = 0V, and since the impedance of a capacitor (capacitance Xc = 1/2pfC) to direct current (f = 0Hz) is essentially infinite, the output voltage is:

$$V_O = V_{BIAS}\left[\left(\frac{R_2}{R_1 + \infty}\right) + 1\right] - 0\left(\frac{R_2}{R_1 + \infty}\right)$$

$$V_O = V_{BIAS}\left(\frac{R_2}{\infty} + 1\right) - 0$$

Because R2 / infinity = 0
We have:
V0 = VBias(0 + 1) = VBias
Vo = VBias

From the above equation we see that the output voltage is equal to the polarization voltage (VBias). Therefore, the voltage at both inputs and the voltage output of the operational amplifier are equal. Due to the presence of the input capacitor, the voltage gain of the amplifier AC now depends on the frequency of the signal applied to the input of the amplifier. The capacitor CIN input and resistor R1 form a high pass RC filter. The values R1 and CIN determine the low cut-off frequency of the amplifier. The frequency at which the voltage gain is decreased by -3dB, is the low cut-off frequency, and can be determined using the following equation:

$$f_{-3dB} = \frac{1}{2\pi R_1 C_{IN}}$$

For example, if CIN = 1pF and R1 = 10Kohm, then the low frequency cutoff is 15.9Hz. Signals having lower frequency than the cutoff frequency, are reduced by 20 decibels (20 decibels per decade) for each tenfold reduction in frequency (one decade corresponds to a ten-fold increase or decrease in frequency). If a capacitor is connected in series with the output, the capacitor will prevent the DC current and will only allow the AC signal to pass, and thus the bias voltage to the load by changing the voltage VBias of the earth (0 volts). The capacitor output together with the load RL forms a low pass RC filter which causes attenuation at low frequencies. Note that although the circuit shown in Figure 16 uses the smallest number of components, may be unsuitable in certain applications where the signal source, the load, and the proper input of the operational amplifier, it must be connected to a bias voltage in such cases should use the circuit shown in Figure 18. Notice that the voltage gain in the circuit shown in Figure 18 depends on agreements frequencies, due to the presence of the input capacitor. You may think that the circuit shown in Figure 18 will work correctly if removing the input capacitor CIN (Fig. 19), but, this capacitor must remain otherwise the circuit will not work correctly. The output voltage of the amplifier in Figure 19 is given by the following equation:

$$V_O = V_{BIAS}\left(\frac{R_2}{R_1} + 1\right) - V_{IN}\left(\frac{R_2}{R_1}\right)$$

The above equation can be proved very simply by using the principle of ultra-rustling, as follows: First we set VBias = 0, the amplifier is now essentially an inverse amplifier and the output voltage is given by the following equation:

VO(-) = VIN x (-R2/R1)
Then we set VIN = 0, the amplifier is now essentially a floor depth in amplifier and the output voltage is given by the following equation:
V0(+) = VBias (1 + R2/R1)
The total output voltage of the amplifier is now equal to:
V0 = V0(-) + V0(+), or Observe that The above equation is the same as Equation 2 if you replace Z1 with R1.

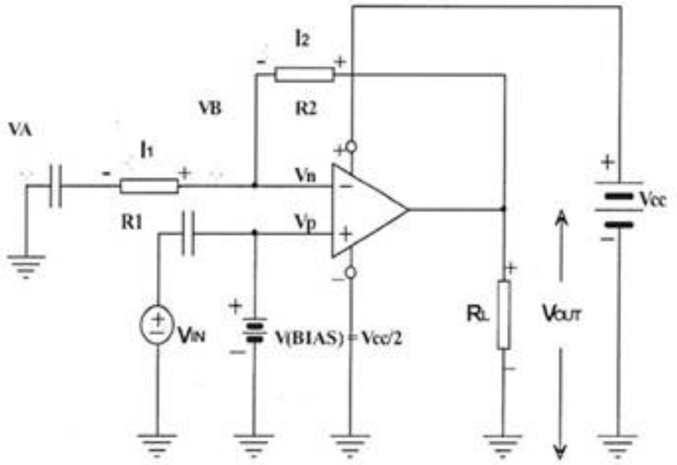


Figure 20. AC amplifier.

In the absence of an input signal, the dc voltage at the output will try to become equal with

$$V_O = \left(1 + \frac{R_2}{R_1}\right) \cdot V_{BIAS}$$

For example, if R1 = R2 = 10Kohm, Vcc = 10V, and VBias = 5V, then:

V0 = (1 +2) VBias = (3)x(5V) = 15V

However, this is not possible because the maximum positive output voltage can have with this amp is less than +10 V.

Therefore, the output voltage is always less than the positive voltage of the power supply. Therefore, when an input signal applied alternating current, the output remains saturated during the negative half-period of the input signal. The output will also remain saturated just below the positive trend of +10 V of power supply, for the positive input signals. The circuit shown in Figure 20 is a correct AC amplifier that operates with a single power supply. The voltage between the reverse and correct input is substantially equal to zero volts. After VN = VD + VP and VD = 0, the input terminal of the reverse is also VBias = Vcc/2, relative to the earth. Therefore, both inputs of the operational amplifier is at the same voltage (VBias). The output voltage can be determined as follows:

The current I1 flowing through Z1 is equal to the current I2 flowing through resistor R2. The voltage across Z1 is equal to VB-VA, where VB = VBias and VA = 0.

So we have:

$$I_1 = \frac{V_B - V_A}{Z_1}$$

$$I_1 = \frac{V_{BIAS} - 0}{Z_1}$$

$$I_1 = \frac{V_{BIAS}}{Z_1}$$

The voltage across R2 is equal to:

Vo = VB: therefore

$$I_2 = \frac{V_O - V_{BIAS}}{R_2}$$

Since I1 = I2, we have:

$$\frac{V_{BIAS}}{Z_1} = \frac{V_O - V_{BIAS}}{R_2}$$

$$\frac{V_{BIAS}}{Z_1} = \frac{V_O}{R_2} - \frac{V_{BIAS}}{R_2}$$

Again rearranging the above equation we take:

$$\frac{V_O}{R_2} = \frac{V_{BIAS}}{Z_1} + \frac{V_{BIAS}}{R_2}$$

$$\frac{V_O}{R_2} = V_{BIAS}\left(\frac{1}{Z_1} + \frac{1}{R_2}\right)$$

By multiplying both sides with R2 we get:

$$V_O = V_{BIAS}\left(1 + \frac{R_2}{Z_1}\right)$$

The impedance Z1 is given by the equation:

$$Z_1 = \sqrt{R_1^2 + X_C^2} = \sqrt{R_1^2 + \left(\frac{1}{2\pi fC}\right)^2}$$

At DC (f = 0Hz), the resistance of the capacitor Cin is infinite:

$$Z_1 = \sqrt{R_1^2 + \left(\frac{1}{2\pi \cdot 0 \cdot C}\right)^2}$$

$$Z_1 = \sqrt{R_1^2 + \infty} = \infty$$

Consequently in DC we get:

$$\frac{R_2}{Z_1} = \frac{R_2}{\infty} = 0$$

and so VO = VBias.

We will now examine the various circuits to generate the dc voltage bias, which is sometimes called virtual ground. Before you choose a circuit output dc voltage bias must specify load regulation, power supply rejection, power dissipation and the output impedance of the circuit bias. The final decision on what bias circuit will be used in an application depends on the cost and the space we have available to us. The simple voltage divider shown in Figure 21, can be used to produce the constant bias voltage (VBias). This circuit has low load regulation. I.e. as the load current increases, the output voltage of this circuit (bias voltage) is reduced. An explanation of the load regulation and line regulation given below.

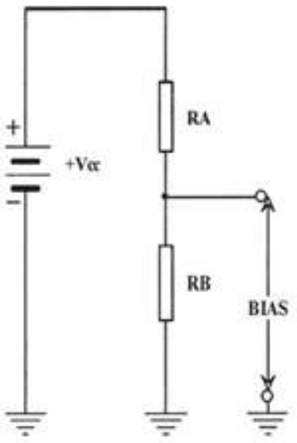


Figure 21. A simple voltage divider can be used to generate the bias voltage (VBias).

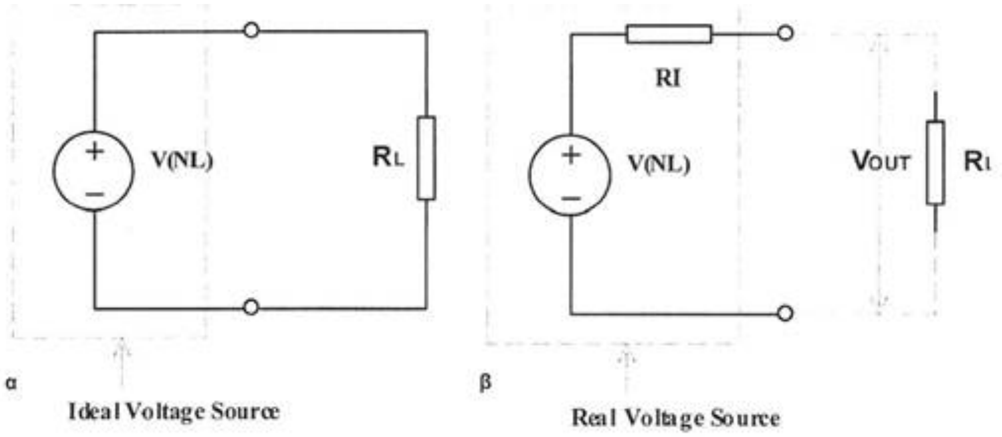


Figure 22(a). Equivalent circuit of an ideal power supply, (b) Equivalent circuit of an actual power supply.

An ideal power supply provides an output voltage that remains constant regardless of the load current, and is also independent of temperature variations, and also from any changes in the supply voltage of the alternating current network. Figure 22A shows the equivalent circuit of an ideal power supply. In the case of a practical power supply, the output voltage decreases as the load current increases. This is why a real power has an equivalent internal resistance, because of the various components of which consists of the power supply circuit. The equivalent circuit of an actual power supply shown in Figure 22b, where VNL is the output voltage with an open circuit (ie the output voltage when there is no load at the output terminals of the power supply), and R1 is the total internal resistance of the power supply. When a load is connected to the output of the power supply, the output voltage, ie the voltage across the load (VL = IL x RL) is less than the output voltage (VNL) with open circuit. This is because the resistors RL, and RI, form a voltage divider and the voltage across the load is given by:

$$V_O = \left(\frac{V_{NL}}{R_I + R_L}\right) \cdot R_L$$

When the load current increases, the voltage drop across the internal resistance RI also increases, and therefore, the output voltage decreases. The reduction of the output voltage as the load current increases, is a disadvantage. The output voltage of a typical power supply compared to the load current is shown in Figure 23. An ideal power supply has an output voltage that is constant regardless of the load that connects to the output terminals. Obviously, if the internal resistance RI is zero or very small compared to the RL, then output voltage VO is constant and equal to the VNL. The change of the DC output voltage of the power supply relative to the continuous load current is called, simply load regulation or regulation.

The regulation is defined as follows:

$$\text{REGULATION} = \frac{V_{NL} - V_L}{V_{NL}}$$

The load regulation can be expressed as a percentage:

$$\%\text{REGULATION} = \left(\frac{V_{NL} - V_L}{V_{NL}}\right) \times 100\%$$

An ideal power supply would have 0 load regulation, since an ideal power supply is:
RI = 0, and therefore VL = VNL.

Example. The open circuit voltage (i.e., when RL = infinity) of a power supply is VNL = 20V, and when a load is connected to terminals of the power supply, the output voltage drops to 15V. The load regulation of the power supply is given by:

$$\%\text{REGULATION} = \left(\frac{V_{NL} - V_L}{V_{NL}}\right) \times 100\%$$

% regulation = [(20V−15V)/20V] x 100%

% regulation = 25%

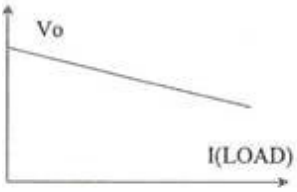


Figure. 23

Ie the regulation of the power supply is 25%.

LINE REGULATION

When the input voltage (supply voltage network) varies, the output voltage of the power supply is also changed. The regulation of the power supply in relation to the changes of the input voltage is called line regulation. The line regulation is defined as the change in output voltage for a given change in input voltage, the load remains constant. The line regulation can be calculated using the following relationship:

$$\text{Line Re g.} = \frac{\Delta V_O}{\Delta V_{IN}}$$

where in DVo is the change in output voltage, and DVin is the change in input voltage (supply voltage network). The D shows a small change.

For example, if the nominal output voltage of a power supply is 10V, and the output voltage is increased by 0.2V (DVo = 0.2V) and when the input voltage rises by 3V (DVin = 3V), then the line regulation is:

$$\text{Line Re g.} = \frac{\Delta V_O}{\Delta V_{IN}} = \frac{0.2V}{3V} = 0.067$$

The circuit shown in Figure 21 has a low regulation because the internal resistance is large. In this example, the internal resistance is equal to the parallel combination of resistors R1 and R2:

R1 // R2 = 1Kohm // 1Kohm = 0.5Kohm

One way to reduce the internal resistance, is to reduce the values of R1 and R2. But, this will lead to a large increase in the direct current, which flows through the voltage divider R1-R2, and the current increase will increase the power consumption in the circuit. Another drawback of this circuit is the low ripple voltage rejection.

RIPPLE REJECTION

Apart from the continuous voltage supplied by an actual power supply, there is also a voltage ripple (an alternating voltage). The voltage ripple may be assumed to be an AC voltage which literally rides the voltage of the power supply as shown in Figure 24. The circuit voltage divider shown in Figure 21, has a very low discharge voltage ripple. To calculate the voltage ripple at the output of the power supply, using the circuit shown in Figure 25. From this circuit we can see that the voltage output wave is given by the following relationship:

$$V_{ro} = V_{ri}\left(\frac{R_2}{R_1 + R_2}\right)$$

If R1 = R2, then we have:

$$V_{ro} = V_{ri} \times \frac{1}{2} = \frac{V_{ri}}{2}$$

Thus, this circuit has a reduction wave is 0.5 or 50%.

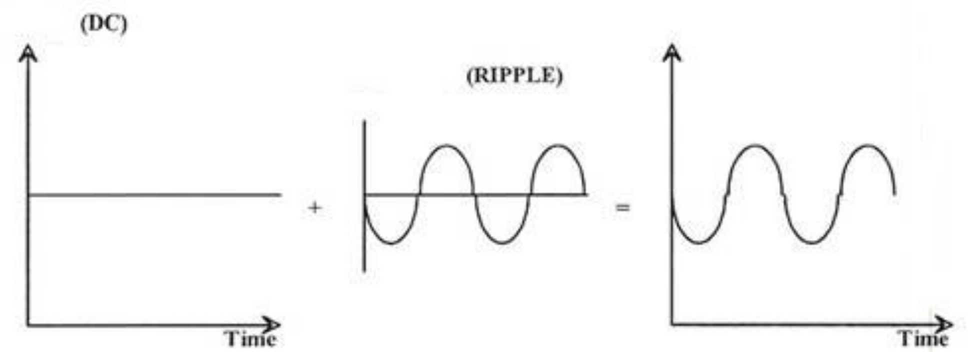


Figure 24. The voltage ripple may be assumed to be an AC voltage which literally rides the voltage of the power supply.

A very popular circuit for producing a virtual ground or bias voltage, with a lower cost than the preceding circuit shown in Figure 26. This circuit consist of a voltage divider (R1-R2), and a capacitor. The main advantage of this circuit is the lowest cost. The disadvantages of the circuit is low load regulation, low voltage power supply rejection (low supply rejection), and high internal resistance.

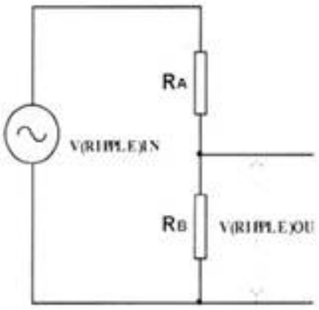


Figure 25. Circuit for the calculation of the voltage wave at the output of the power supply.

Due to the relatively high internal resistance (R1//R2), if the load of the amplifier be connected to the virtual ground, as shown in Figure 27, then any large change in the load will cause the value of VBias be changed (because when the load current increases the voltage VBias is reduced). Furthermore, a large percentage of the voltage wave generated by the power supply will enter the system.

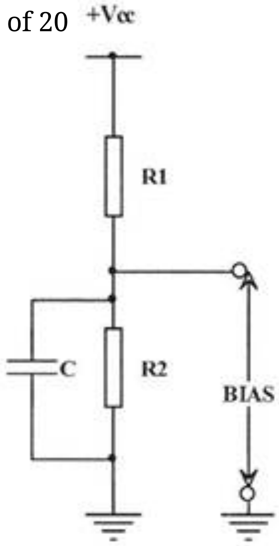


Figure 26. Circuit for producing virtual ground or voltage polarization, consists of a voltage divider (R1-R2), and a bypass capacitor.

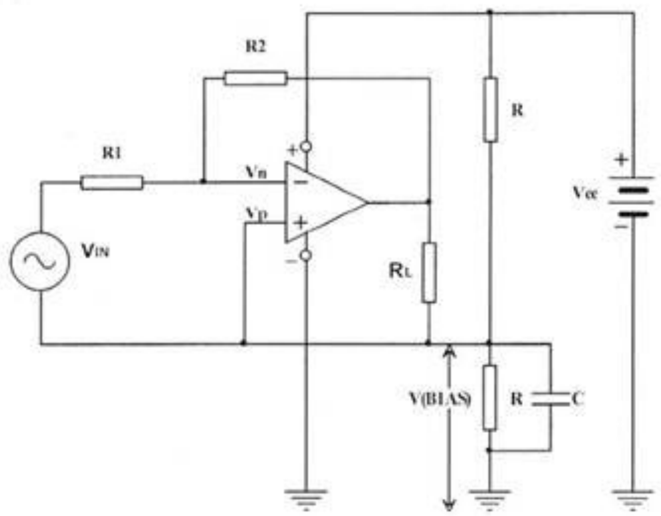


Figure 27.

RIPPLE REDUCTION

Because the circuit takes its power from the main power supply rail (+ Vcc), a certain amount of ripple will be present in the rail. By connecting the capacitor the the ends of the resistor R2 the ripple which appears at the output is reduced.

For example, if C = 100mF, and R1 = R2 = 1Kohm, then the capacitance of capacitor ripple frequency (100Hz in the case of a power supply with full-wave rectification) will be:

$$X_C = \frac{1}{2\pi fC} = \frac{1}{(2\pi)(100\text{Hz})(100\mu\text{F})}$$

$$X_C \approx 16\Omega$$

Therefore, the output voltage ripple is given by:

$$V_{ro} = V_{ri} \times \left(\frac{Z_2}{Z_2 + R_1} \right)$$

where Z2 = R2 // Xc = 16ohm, so we have:

$$V_{ro} = V_{ri} \times \left(\frac{16\Omega}{16\Omega + 1000\Omega} \right)$$

$$\frac{V_{ro}}{V_{ri}} = \frac{16}{1016} \cong \frac{1}{63.5}$$

The voltage ripple of the power supply is reduced by a factor of 1/63.5.

For example, if the wave of power supply is 100mV, then the ripple at the output will be about 1,6 mV. Without the capacitor ripple would be reduced by 50% (0.5,) and the ripple in the output will be 50mV.

Notice that when the capacitor is at the ends of the resistor R2, the voltage ripple is reduced only if the capacitance of the capacitor (Xc = 1/2piO) is much less than the value of resistor R2. Therefore, the greater the capacitance of the capacitor, the better the rejection Wave. But, a larger capacitor increases the size and cost of the circuit. The power concumption of voltage devider can be calculated using the folloing formula:

PD = VCC x I

Where VCC is the voltage of the power supply and the current comes from the following formula:

$$I = \frac{V_{CC}}{R_1 + R_2}$$

So we get:

$$P_D = V_{CC} \times \left(\frac{V_{CC}}{R_1 + R_2} \right)$$

$$P_D = \frac{V_{CC}^2}{R_1 + R_2}$$

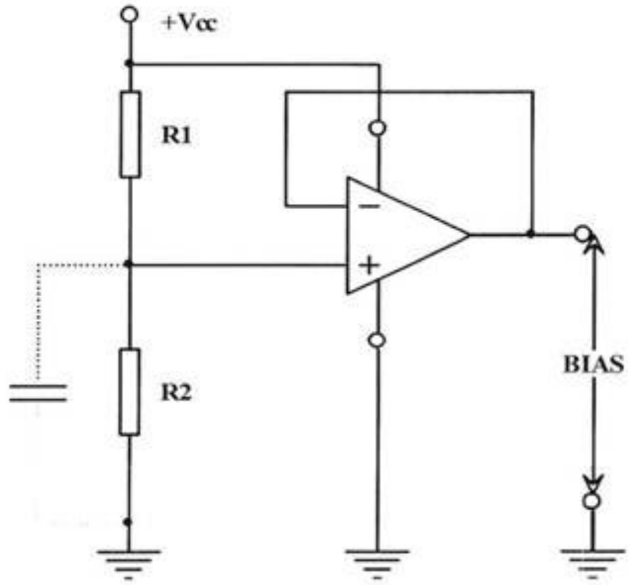
For example: If R1=R2=R=2Kohm and VCC=10V the power consumption is:

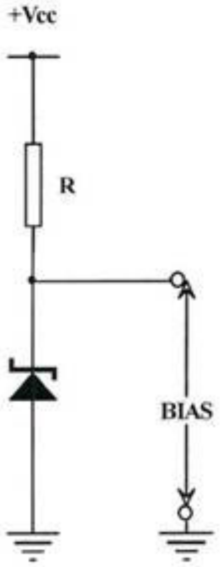
$$P_D = \frac{10^2}{4K\Omega} = \frac{100}{4000} = 0.025W$$

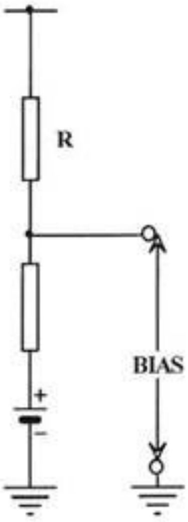
or 25mW. To reduce the power consumed must increase rates of R1 and R2. But, with increasing values of the resistors R1 and R2, the internal resistance of the power supply and thus the voltage regulation of the circuit gets worst. The circuit shown in Figure 28 uses an isolation amplifier and has a very good load regulation. In this circuit the output impedance of the circuit polarization is equal to the output impedance of the isolation amplifier, which gets usually very small. An isolation amplifier voltage with gain 1 has a very high input resistor and a very low output impedance. Because the output impedance of the circuit does not depend on R1 and R2, these values can be increased without having any influence on the resistance significant output (internal resistance) of the circuit, and to the load regulation. Increasing the values of resistors R1 and R2 the power consumed in the voltage divider R1-R2 decreases. But, the power consumption is relatively large and this circuit is not very suitable for portable applications.

This circuit is able to supply a changing-states load, while the output voltage remains relatively constant. But the rejection Wave of the power supply remains the same with the circuit shown in figures 21 and 26.

A major disadvantage of this circuit is the additional cost of operational amplifier used as isolator, and the relatively large space in PCB, required for the isolation amplifier. Also, the current supply required for the amplifier reduces battery life in portable applications.







Bias Voltage using ZENER

The circuit shown in Figure 29a use a resistor in series with a Zener diode for produce the DC voltage bias. A zener diode maybe used as stabilization voltage. The characteristic of a zener diode and the equivalent circuit is shown in Figure 30. From the characteristic see that the zener diode has a fixed dynamic resistance, Rz, in a particular area of values, from Iz(min) to Iz(max). We know that a voltage supply of good quality should have a low internal resistance, thus if the zener diode is to be used as a reference voltage, then the internal resistance Rz should be small. This occurs when the zener current is within a particular region Iz(min) to Iz(max). Outside this region Rz increases.

Therefore, if the zener diode is to operate as reference voltage (constant voltage source), with a good load regulation, the zener current must not fall below Iz(min) or higher than Iz(max).
From theequivalent circuit of zener in Figure 29b we have:

$$V_{IN} = (I_Z \times R) + (I_Z \times R_Z) + V_Z$$

$$V_{IN} - V_Z = I_Z\,(R + R_Z)$$

Solving for Iz we get:

$$I_Z = \frac{V_{IN} - V_Z}{R + R_Z} \quad (4)$$

Therefore, the reference voltage, or bias voltage, VBias, is equal to:

VBias = (Iz x Rz) + Vz

By substituting Iz from equation 4 is obtained:

$$V_{BIAS} = \left(\frac{V_{IN} - V_Z}{R + R_Z}\right) \cdot R_Z + V_Z$$

where Vz = the breakdown voltage (breakdown) zener, Iz is the current zener, and Rz is the resistance zener.

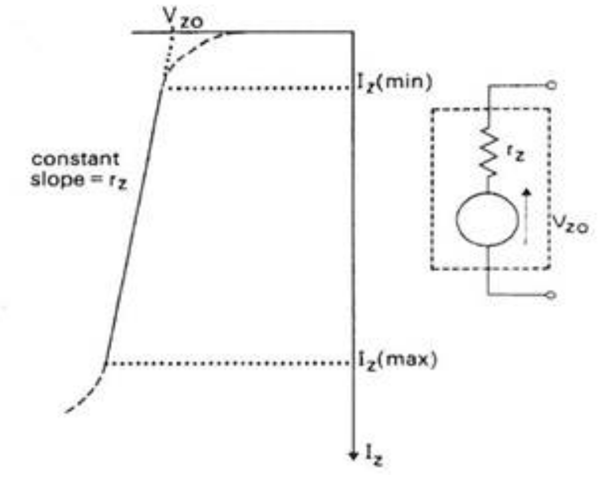


Figure 30. Characteristic curve, and an equivalent circuit of the diode Zener.

Changes in voltage cause changes in the current of zener, thereby changing the value Vz, and therefore to the voltage bias (VBias). The reference voltage, and therefore the bias voltage, varies as the temperature changes. For example, suppose that a passage has a nominal value 6.2V at 25°C, and the temperature coefficient of the zener is +2.2mV/°C (by deep per degree centigrade), then if the temperature of contact zener increased to 125°C, the voltage zener, and therefore the bias voltage will increase by:

$(125^{0}C - 25^{0}C) \times 2{,}2\ mV/^{0}C = 220mV.$

So the reference voltage(bias) will be 6,2 + 0.22V = 6.42V.

VOLTAGE RIPPLE REGECTION

To calculate the voltage ripple rejection circuit, using the equivalent circuit shown in Figure 31. The output voltage ripple, Vro is given by the following relationship

$$V_{ro} = V_{ri} \times \left(\frac{R_Z}{R_1 + R_Z} \right)$$

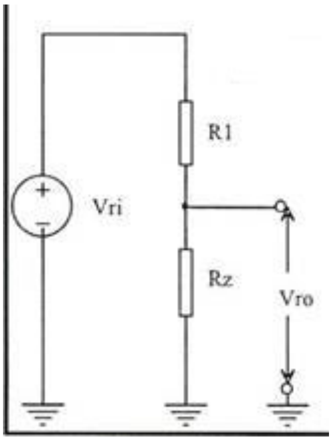


Figure 31.

For example, if Rz = 5ohm, and R =250ohm, then at the output will have a reduced ripple of about 1/51, ie:

$$\frac{V_{ro}}{V_{ri}} = \frac{R_Z}{R_1 + R_Z} = \frac{5}{5+250} = \frac{1}{51}$$

While with the divider circuit voltage we have a reduction wave (ripple reduction factor) of 1/2 or 50%. If we want to further reduce the ripple of the power supply, connect a capacitor across the zener diode as shown in Figure 32. But, the voltage ripple is reduced only if the capacitance of the capacitor is much less than the resistance (Rz) of the diode zener (RZ) at the alternating current. This means that the value of the capacitor must be very big.
The main disadvantage of this circuit is at the high power consumption.

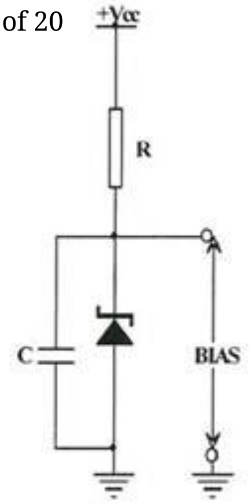


Figure 32.

This is due to a relatively high current (a few milliamperes), which should be flowing through the zener diode constantly, and this increases the power consumption. Due to the high power consumption, this circuit is suitable for portable applications.

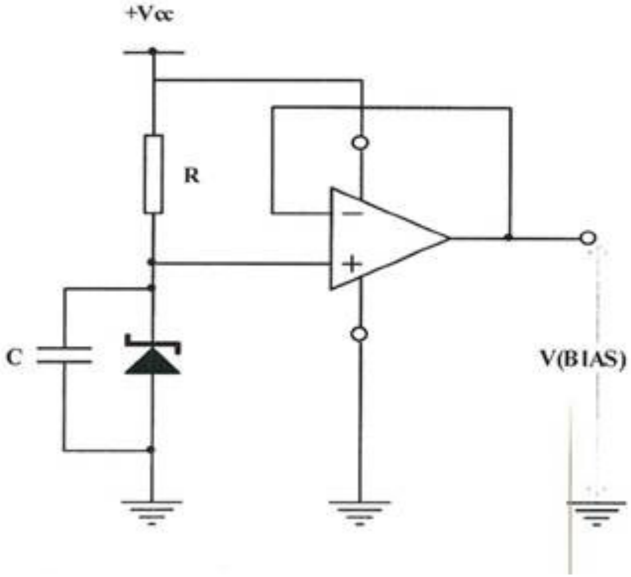


Figure 33.

The load regulation circuit with the zener diode can be improved by using an isolation amplifier as shown in Figure 33. This circuit provides good load and input regulation, but the high power consumption, additional accessories and extra costs must be taken into consideration before you decide to use this circuit.

IC REFERENCE VOLTAGE

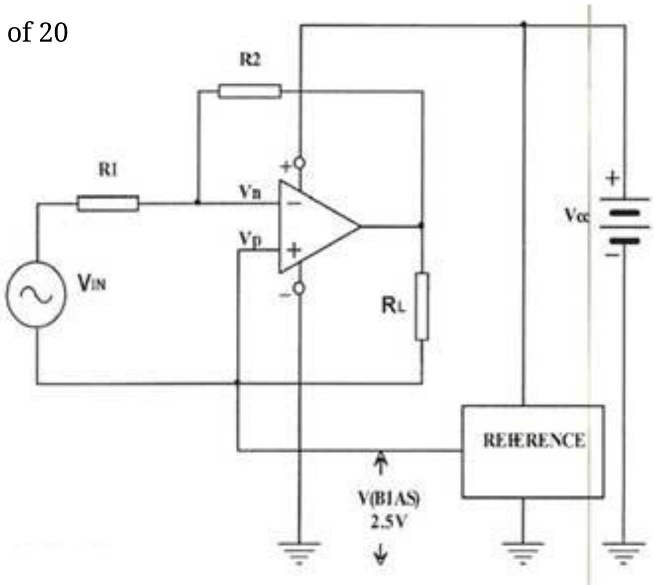


Figure 34.

You can also use one chip voltage reference as the TLE2425 by Texas Instruments (figure 34), which is suitable for operational amplifiers, and operates with a single power supply of 5V. The voltage reference provides a continuous bias voltage of 2.5V, and if the input voltage applied to the integrated circuit does not fall below 4V, the voltage at output terminal remains at 2,5V. Generally, the circuit used to generate the constant bias voltage depends on the application. If an application requires a high current, then you should choose a source of DC bias voltage isolation amplifier with one who has a good regulation, so that the bias voltage will not demoted from the high load current. If on the other hand, the system requires a low current, the source voltage using the zener diode may be suitable. Finally, if the most important parameter is the low cost, then a simple voltage divider with a capacitor to be used.

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